THE CONCENTRATION OF ROOTS IN THE WHITE OAK FORESTS OF SOUTHEASTERN OHIO

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TECHNICAL PAPER NO. 120

MARCH 1951

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Introduction

An important function of roots is the absorption of water and mineral nutrients. Of the water and nutrients available in the soil, the quantity absorbed depends largely upon the extent and efficiency of the root system. This is a report on the concentration of the roots of white oak (Quercus alba L.) growing in forest stands, and the influence of some characteristics of the forest stand and the soil profile on the development of root systems.

Information on the extent of the root systems of mature, forest-grown trees is fragmentary. Much of the data has been obtained by excavating root systems and, because the method is costly, relatively few observations have been made. Weaver and Kramer (14) report that the roots of mature, forest-grown bur oak (Q. macrocarpa Michx.) trees extend laterally 20 to 60 feet and vertically to a depth of 14 feet through soil of fairly heavy texture (Carrington silt loam). Three-year-old bur oak saplings growing on forest sites in Nebraska (8) had root systems 2.3 to 8.5 feet deep and 0.8 to 3.2 feet in lateral extent. Saplings of the same species growing under forest conditions in Missouri (1) had developed taproots 15 feet long at the age of 8 years. The early development of a deep and extensive root system by saplings of certain other species of deciduous forest trees is reported by the same observers.

A 250-year-old longleaf pine (Pinus palustris Mill.) growing on a sandy soil (Norfolk sand, deep phase) in western Florida is reported (7) to have had a taproot more than 14 feet long and lateral roots up to 75 feet long. Longleaf pine saplings growing in the same vicinity had root systems penetrating to a depth of 9 feet. Lateral roots of pitch pine (P. rigida Mill.), 12 to 30 years old, growing on sandy soils (Lakewood sand and Sassafras series) in New Jersey attained a length of 25 to 35 feet (9).

The concentration of roots less than 0.1 inch in diameter in five forest types occurring on the lower Piedmont of North Carolina has been reported by Coile (4). He found that root concentration increased rapidly in the top two soil layers (A_1 and A_2 horizons) during the first 20 to 30 years of the pine stage in the succession toward an oak-hickory climax forest. After that, changes in concentration were slow. Concentrations in subsoil horizons remained constant after the pine was 20 years old. In addition, he noted that the weight of roots in a fixed volume of soil was

the same in a pine and in a hardwood forest occurring on quite different soils, suggesting that the soil has a root capacity under certain conditions.

From Miller's (10) review of the literature dealing with the factors influencing the extent and development of root systems of field and orchard plant species, it appears that the root systems of agricultural plants tend to extend laterally as the stand is thinner; that downward growth is limited by soil aeration and moisture and the species and age of plant involved; that the number of roots is proportional to the availability of nutrients but inversely proportional to soil moisture, and that compact soils reduce root extension and development.

Weaver (13) remarks that root stratification is often due to soil texture. The coarser surface soil horizons (4), for example, frequently have high root concentrations. This may not be true in the higher latitudes where surface horizons can be cemented.

Holch (8) notes that the root growth of certain deciduous tree seedlings was inversely proportional to the water available in the soil. The influence of climate, soil, and forest stand characteristics on the root growth of mature forest trees is largely unknown and profitable research can be performed in this field.

The Region

Southeastern Ohio lies in the western part of the Appalachian Plateau where the topography varies from rolling to steeply hilly. The climate is characterized by hot summers and mild winters; the growing season is about 160 days. Precipitation, nearly all in the form of rain, is well distributed through the year and averages 40 inches.

The soils investigated in this study belong to the Muskingum-Wellston-Zanesville association of the gray-brown podzolic soils (12). These soils are derived from sandstone and shale parent materials. The Muskingum series occurs on the steeper slopes; the soil mantle is shallow, contains a high proportion of rock fragments, and shows very little horizon differentiation except for the parent material and the organic layer. The Wellston and Zanesville series are found on gentler topography and horizon differentiation is marked. Internal drainage varies from moderate to slow in the Muskingum series to very slow in the Wellston and Zanesville series. Surface drainage is excellent for all soils.

Forests of deciduous tree species formed the native vegetational cover. The present forests have developed on abandoned agricultural land or have regenerated naturally following cutting. Extensive areas of even-aged forest stands exist as a result of clear-cutting to obtain wood for charcoal production. The oaks are the dominant genus from the standpoint of frequency in commercial sizes, and of these, white oak is the most common.

Methods

Twenty-six even-aged forest stands were selected as locations for soil wells from which data on the distribution and concentration of roots were obtained. Each stand contained some white oak in the overstory. The mean age of the stands varied from 30 to 114 years. A variety of topographic and soil conditions were represented. An upland forest stand is shown in figure 1.

Figure 1.--A white oak forest on an upper slope. The stand is 73 years old, the mean height of dominant white oaks is 62 feet, and stand density is 98 percent of average.

Figure 2.--A soil well located in a white oak stand on bottomland. Note the grocer's-twine grid used in mapping root concentrations.

Soil wells were located with one end of the vertical face tangent to the taproot of a dominant white oak. The face of the well extended outward from the reference tree along a contour. The wells were 140 inches long, about 40 inches deep except where bedrock was encountered at a shallow level or where relatively high concentrations of roots were found deeper, and about 30 inches wide. A 10-inch grid (grocer's twine) was affixed to the face of the well as shown in figure 2. Roots were mapped on a scale reduced tenfold except that roots one-fourth inch in diameter or smaller were represented by dots. Boundaries of all soil horizons were mapped.

Undisturbed soil samples of known volume (5) were obtained from the horizons of four of the stands so that cross-sectional concentrations of roots could be expressed as weights. The oven-dry (24 hours at 105° C) weight of roots one-fourth inches and smaller in diameter found in each sample was computed as a linear function of the concentration of these smaller roots as mapped on the well face. Due regard was taken for the cross-sectional area and volume of the sample. The mapped concentrations were converted to weight in tons per acre-foot by dividing the frequency per square foot by 20.[1]

Samples of disturbed soil were also obtained from the principal horizons. The air-dry soil was prepared for analysis by sieving through a screen having openings 2 millimeters in diameter. For all horizons,[2] mechanical composition was determined by the hydrometer method (2), moisture equivalent by centrifugation, and permanent wilting percentage by using wheat plants as indicators.

The percentage of water remaining in the soil at the time of permanent wilting gives some indication of the amount of water unavailable to plants because of the nature of the soil. Although some water may still be available to the plants at this time, it is not enough to keep them alive. Soils, of course, differ in their ability to hold water. Clay soils, for example, hold more water than coarser soils at the permanent wilting point.

About 100 wheat plants were germinated and grown in two-thirds pints of soil contained by a cylindrical, low form, pint-size, paraffinized ice-cream container. After the plants were 7 inches high, the soil surface was sealed with paraffin. Permanent wilting was marked by total collapse of the plants and a partial curling of some of the blades. Recovery did not occur in an atmosphere saturated with water vapor. Excellent root development was obtained in every case but germination was delayed in the very fine-textured soils.

1/ Weight (tons per acre-foot) = 0.049 concentration (frequency per square foot).

2/ A_1 horizons were not deep enough to provide samples except at 9 places.

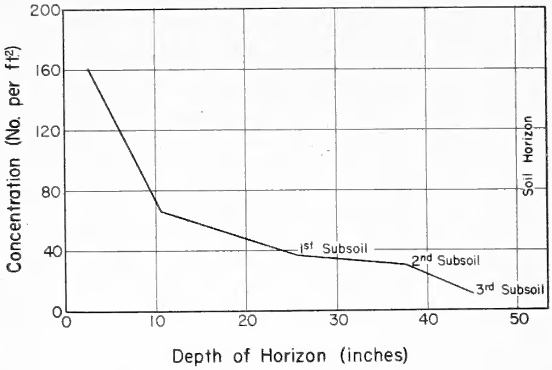
Results

The concentration of roots one-fourth inches and smaller in diameter decreases rapidly with increasing depth of the soil horizon (table 1 and figure 3) but relatively high concentrations will be found in the subsoil horizons if the concentration in the A_2 horizon is high (figure 4). The concentration in A_1 horizons exceeds that in the A_2 horizons by $2\frac{1}{2}$ times while the concentration in the first subsoil horizon (B_1 or C_1) is about half that of the A_2. It is interesting to find that the change in concentration with the depth and the volume weight of the horizons is linear if plotted upon a log-log scale. The greater volume weight of deeper horizons hinders root growth and slows down aeration. However, horizon depth in itself does not limit root concentrations; in the absence of an A_1 horizon, the concentration in the A_2 horizon does not approach the average for A_1 horizons. It is possible, of course, that the high concentration of roots in the A_1 horizon is related to the high level of available nutrients in that horizon.

Table 1.--The concentration of roots by soil horizons

Horizon	Mean concentration of roots ($\frac{1}{4}$ inch and smaller in diameter) per square foot of well face	Average volume weight (water = 1.00)	Average depth (inches)	Average thickness (inches)	Product of concentration and thickness
A_1	160	0.94 ± 0.03	2.7	2.7	432
A_2	66	1.24 ± 0.03	10.9	8.2	541
Total					973
1st. subsoil	37	1.48 ± 0.03	25.7	14.8	548
2nd. subsoil	28	--	37.7	12.0	336
3rd. subsoil	12	--	44.8	7.1	85
Total					969

If the product of mean concentration and average horizon thickness is considered, the total number of smaller roots in the A_1 and A_2 horizons equals the number found in subsoil horizons, despite the fact that the soil volume in the A horizons is small compared with the subsoil volume containing roots. On the average, the weight in tons of smaller roots per acre-foot is 7.8, 3.2, 1.8, and 1.4 for the A_1, A_2, first, and second subsoil horizons respectively. The first three feet of the average profile contains about 7.4 tons per acre of roots one-fourth inch and smaller in diameter.



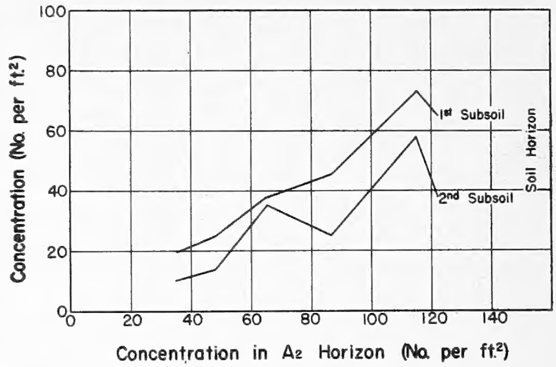
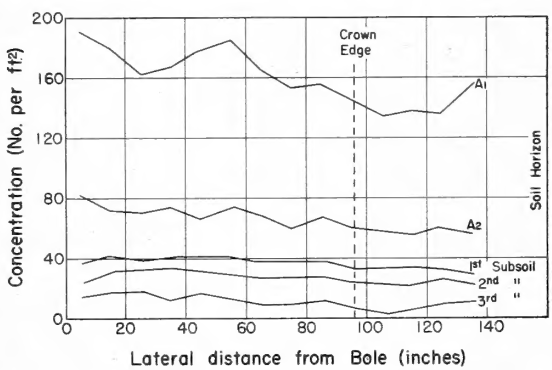


Figure 3.--The concentration of roots in various soil horizons.

Figure 4.--The relation of root concentrations in subsoil horizons to the concentration in the A_2 horizon.

The concentration of smaller roots is higher near the trunk of white oak trees than under the edge of the crown. This is true in all soil horizons. The concentrations are lowest beneath the edge of the crown. The lateral concentrations of smaller roots and the mean extent of the crown are shown in figure 5. The rate of decrease in lateral concentration is greatest in the A_1 horizon and is slower in other horizons.

Root concentrations appear to be greatest some 2 to 5 feet out from the trunk of the tree in subsoil horizons. Why root concentrations are not uniform is not clear. Apparently the soil regions farther away from the trunk are less fully occupied by roots. It may be that the capacity of roots to absorb water and nutrients is unsatisfied; a few roots may be able to absorb as much as several under certain conditions. If root concentrations are expected to be inversely related to the moisture reaching the soil, it could be argued that because more water reaches the ground between the crown fewer roots are found there. For the same reason root



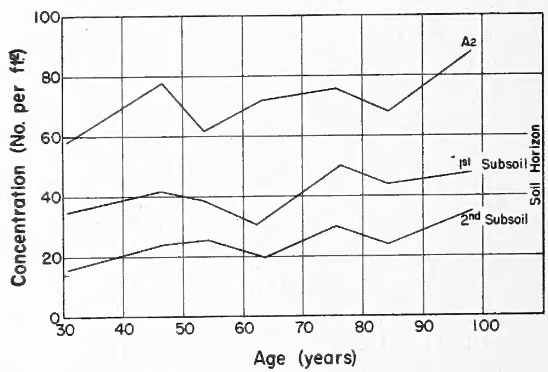


Figure 5.--The relation of root concentration to the lateral distance from the bole. The average extent of the crown is shown by a broken, vertical line.

Figure 6.--The relation of root concentration to age (trees 30 years and older).

concentrations at the base of the trunk should be low as a result of the stem-flow of water, but this is not the case in surface horizons where variations in moisture are greatest. Although we lack an adequate explanation for the pattern of root concentrations, we can use it in further studies of root concentrations in forest stands.

The concentration of smaller roots cannot be shown as a significant function of age (tree and stand ages are identical) although the grouped data show a trend toward higher concentrations at the older ages (figure 6). For all practical purposes, root concentrations do not change after white oak stands reach age 30. This agrees with results obtained by Coile (4).

Root concentration in itself appears to have little influence on growth. The best sites do not differ perceptibly from the poorest so far as root concentrations are concerned (figure 7). If anything, concentrations are higher in poorer land. However, the quality of land for growing white oak depends upon the depth of the A horizon (6). Differences in site quality arise not because roots fail to occupy the soil mass, but because the volume of soil favoring high concentrations of roots can be great or small.

This conclusion is backed by studies in which bole volume growth of individual white oak trees (tangent to each soil well) was compared with root concentrations in the A_2 and first subsoil horizons. Bole volumes had to be corrected to a common age since the trees ranged from 30 to over 100 years in age. This was done by computing the present bole volume (11), and these volumes (logarithmic units) were expressed as a function of age (reciprocal units). The difference between the real or present volume of each tree and its volume estimated as a function of age represents the effect, beyond the average, of all environmental and genetic factors influencing growth (and some error). The volume difference is plotted against root concentration in figure 8; no perceptible relationship can be seen between

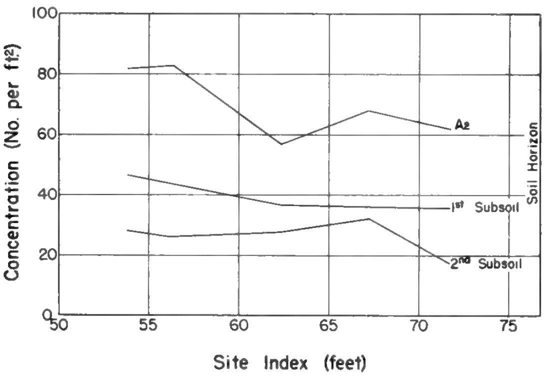


Figure 7.--The relation of root concentration to site quality.

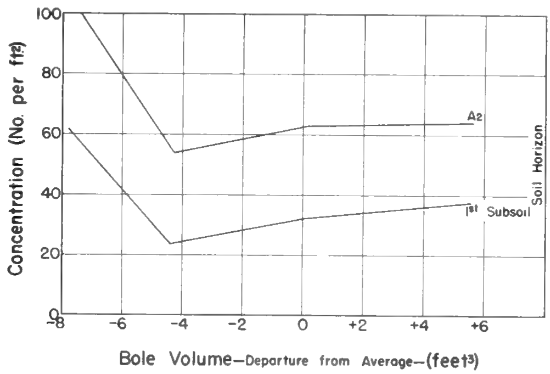


Figure 8.--The relation of bole volume growth to root concentration.

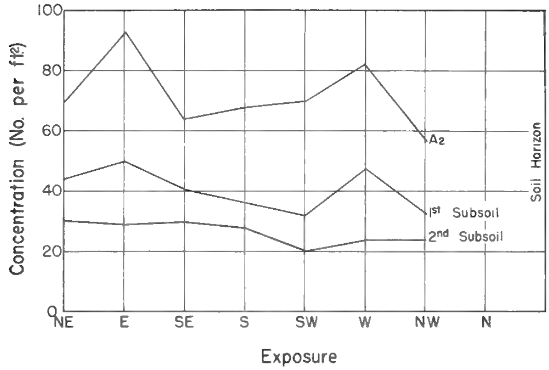


Figure 9.--The relation of root concentration to topographic exposure.

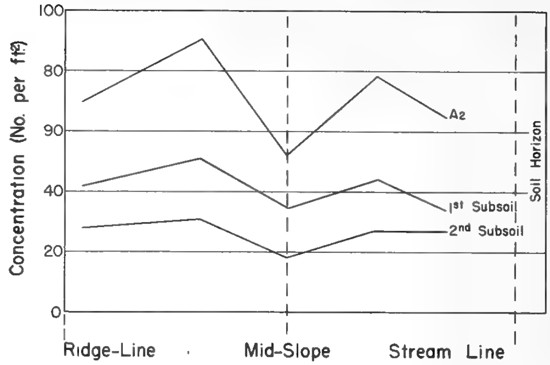


Figure 10.--The relation of root concentration to on-slope position.

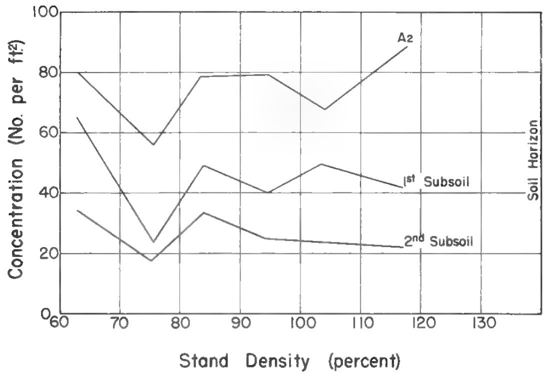


Figure 11.--The relation of root concentration to stand density.

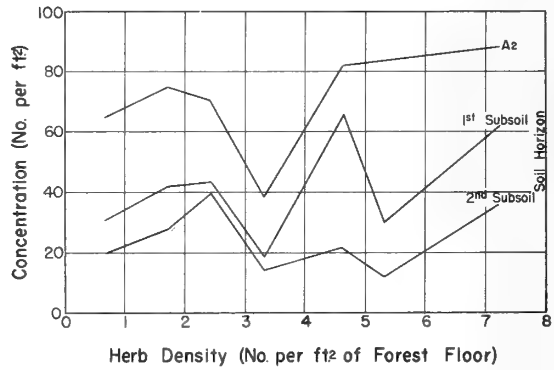


Figure 12.--The relation of root concentration to herb density.

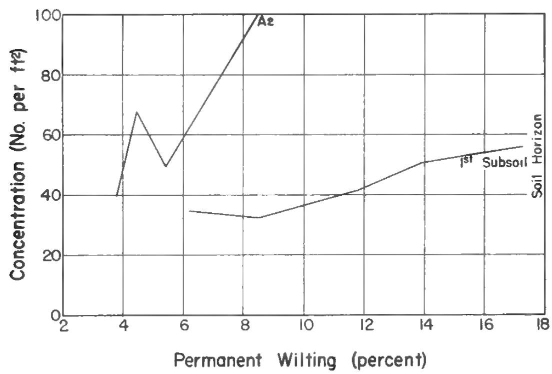


Figure 13.--The relation of root concentration to the permanent wilting percentage of the A_2 and first subsoil horizons.

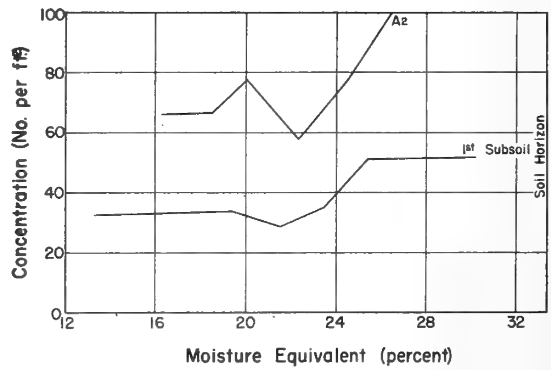


Figure 14.--The relation of root concentration to the moisture equivalent of the A_2 and first subsoil horizons.

volume growth beyond the average and root concentration. The conclusion reached in the preceding paragraph can be restated; the mere concentration of roots shows no perceptible relationship to above-ground volume growth of white oak.

The topography of land does not appear to affect the concentration of roots (figures 9 and 10). The moister sites, lower slopes and northerly exposures, which are better for white oak growth (6), do not support higher concentrations of roots than do the drier sites. That root concentrations do not vary greatly with topography is not in itself surprising. The fact that white oak grows faster on the moister sites must mean that the capacity of roots to absorb water and nutrients is unsatisfied on the drier sites but more completely satisfied on the moister locations.

Neither density (3) of the forest stand nor the density of the herbaceous cover can be shown to affect the concentration of roots (figures 11 and 12). This upholds the concept that the soil has a capacity (4) to support roots. The application of this concept in forest management is obvious: when a forest is thinned, the remaining trees should grow more rapidly (within reasonable limits).

The concentration of roots was observed to vary strikingly between the several stands. This variation is not due to chance but, within A_2 horizons, is significantly related to the permanent wilting percentage (figure 13). The moisture equivalent (figure 14), the availability of water (figure 15), and soil texture (figure 16) appear to influence root concentrations but not at statistical levels of significance. Because these soil characteristics are intimately related, it seems likely that any of them could be shown to affect root concentrations given sufficient data In general, soil characteristics such as horizon development, the volume weight of the horizons, and the moisture constants set the limits on root concentrations in white oak stands over 30 years of age.

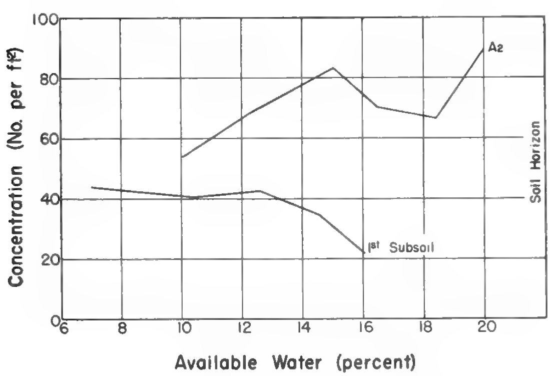


Figure 15.--The relation of root concentration to the availability of water in the A_2 and first subsoil horizons.

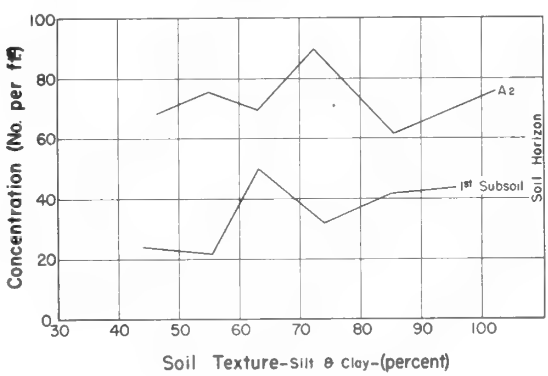


Figure 16.--The relation of root concentration to the texture of the A_2 and first subsoil horizons.

To this point, the single effects of age, permanent wilting percentage, etc., on root concentration have been considered. It is possible that the cumulative effect of these variables might be significant. The combined influence of four variables on root concentrations in A_2 horizons was tested. They were: age, site quality, stand density, and permanent wilting percentage. The first three variables were selected because they are known to affect or be related to above-ground tree growth. The soil variable is included because of its demonstrable effect on root concentration. The result of the analysis is presented in table 2; the cumulative effect of all variables except the permanent wilting percentage is not significant.

Table 2.--The influence of certain factors on the concentration of small roots in the A_2 horizons under even-aged stands of white oak in southeastern Ohio: an analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratio	Level of significance
					Percent
Regression on permanent wilting percentage alone	1	3469	3469	6.19	5
Added effect of the regression on age, site quality, and stand density	3	175	58	0.10	--
Residual error	17	9521	560	--	--
Total[1/] corrected	21	--	--	--	--

1/ A_2 horizons were absent at four places.

Discussion

The results of this study are sufficient to indicate the effect of some soil, topographic, and stand characteristics on the concentration of smaller roots. These results may have direct application to future research in forest influences, particularly with respect to the transpiration of water by forest stands and the organic enrichment of soil horizons. They are now useful in supplying a partial explanation for differences in the quality of land for the above-ground growth of white oak. One of the writers has found that superior sites occur on lower slopes with northerly exposures, whose A horizons are deep, or high in total available water (6). A deeper A horizon allows a greater total number of smaller roots to develop and, presumably, this permits larger amounts of water and nutrients to be absorbed. And as water availability increases so do both site quality and the number of smaller roots per unit volume of A horizon. Why lower slopes and northerly exposures are superior sites cannot be explained in terms of root concentrations or numbers of smaller roots. Perhaps the capacity of roots to absorb is more nearly satisfied on the wetter than on the drier sites.

Summary

The concentrations of the smaller roots of white oak growing in even-aged forest stands in southeastern Ohio were measured by the soil-well method. The data were taken from 26 stands of differing but known site quality and tree density. The depth, texture, moisture equivalent, permanent wilting percentage, and available moisture were measured by direct methods for all soil horizons containing roots.

Findings:

1. The weight of roots having a diameter of one-fourth inch or less amounts, on the average, to 7.8, 3.2, 1.8, and 1.4 tons per acre-foot in the A_1, A_2, first, and second subsoil horizons, respectively. The first 3 feet of an average soil profile contains about 7.4 tons per acre of smaller roots.

2. The concentration of roots one-fourth inch and less in diameter decreases rapidly in succeedingly deeper horizons.

3. The lateral concentration of smaller roots reaches a minimum beneath the edge of tree crowns.

4. Where the concentration is high in the A_2 horizon, relatively high concentrations are found in deeper horizons.

5. Root concentrations are nearly constant after well-stocked white oak stands reach the age of 30 years.

6. Neither site quality, topography, nor stand and herbaceous cover density perceptibly affect root concentrations. Root concentrations are influenced by the permanent wilting percentage in the A_2 horizons and it is likely that the volume weight, availability of moisture, and other soil characteristics affect concentrations in that and other horizons.

7. The above-ground growth of white oak in bole volume does not bear a perceptible relation to the concentration of smaller roots.

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